AFRL-RV-HA-TR-2008-1108

Vector Fluxgate Magnetometer (VMAG) Development for DSX

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Scientific Report No. 3

19 May 2008

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
19-05-2008	Scientific Report No. 3	April 2007 - April 2008

4. TITLE AND SUBTITLE
Spacecraft Instrumentation to Measure and Stimulate Space Particles and Plasma Waves in the Medium-Earth Orbit

5a. CONTRACT NUMBER
FA8718-05-C-0025

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62601F

6. AUTHOR(S)
Mark B. Moldwin

5d. PROJECT NUMBER
1010

5e. TASK NUMBER
RR

5f. WORK UNIT NUMBER
A1

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
UCLA
Institute of Geophysics and Planetary Physics
Department of Earth and Space Sciences
3845 Slichter Hall
Los Angeles, CA 90095-1567

8. PERFORMING ORGANIZATION REPORT NUMBE

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
29 Randolph Road
Hanscom AFB, MA 01731-3010

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/RVBXR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RV-HA-TR-2008-1108

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
UCLA is building a three-axis fluxgate magnetometer for the Air Force Research Laboratory (AFRL) mission. The instrument is designed to measure the medium-Earth orbit geomagnetic field with precision of 0.1 nT and provide the field direction to within 1 degree. The instrument will provide the DC magnetic field for phase space density calculations of energetic particles, the magnetic field vector information for the Loss Cone Imager (LCI) payload, and the ULF wave environment. The project is on schedule for flight unit delivery in July 2008.

15. SUBJECT TERMS
Space Instrumentation, Magnetometer, Radiation belts

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	SAR	25	Daniel L. Elsner, 2dLt
					19b. TELEPHONE NUMBER *(include area code)*

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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1. INTRODUCTION

This effort is in response to the Battlespace Environment Division, Space Vehicle Directorate, Air Force Research Laboratory's (AFRL) request to develop and provide a vector fluxgate magnetometer to support both the Space Weather (SWx) and Wave Particle Interaction (WPIx) payloads on the Demonstration and Science Experiment (DSX), which will be launched into the Medium-Earth Orbit Space Environment Regime.

Included as part of the DSX payload is a vector magnetometer. The vector magnetometer provides measurements of the terrestrial field, which is essential to fulfill the two primary goals of the DSX science program. The fluxgate magnetometer provides the necessary data to support both the Space Weather (SWx) specification and mapping requirements and the WPIx requirements. The magnetic field is necessary to reconstruct pitch-angle distributions (PADs), to calculate phase space densities, and to determine important local plasma parameters such as plasma beta and the local index of refraction. The fluxgate magnetometer provides measurements of the magnetic fields caused by currents that flow into and above the Earth's ionosphere. These currents close with currents in the Earth's magnetosphere, via field-aligned currents, and measuring these currents is essential for improvements in magnetospheric specification models.

This Report describes UCLA's year 3 effort (April 2007 – March 2008) in designing and building the Engineering Unit of the vector magnetometer for the DSX program. This magnetometer is based on the fluxgate design that has been developed over the years by UCLA. We have developed a magnetometer that easily conforms to the DSX requirements (as specified in L0/L1 Requirements Document and Common Requirements Document Rev D), with a high degree of reliability and a low impact on spacecraft resources in terms of mass, power, and volume.

This report briefly summarizes our activities, accomplishments, and lessons learned during this year. The reader is referred to the Year 1 and 2 Annual Reports (AFRL-VS-HA-TR-2006-1079 and AFRL-RV-HA-TR-2007-1077) for a description of the science objectives and heritage of the instrument and the initial development of the engineering unit. Other information regarding the VMAG instrument is found in the Preliminary Design Review and Critical Design Review documentation submitted to the DSX Project Management Office (PMO) as part of the regular reporting process.

2. BACKGROUND

This section provides some background and introductory material. The subsequent sections present a summary of the activities conducted for this project this past year. In Section 3, we present the magnetic specification developed for DSX. Section 4 contains a narrative of the design and hardware development accomplishments during this reporting period.

2.1. Science Rationale

As an educational institution, UCLA's primary motivation in providing fluxgate magnetometers for DSX is directed to the scientific return from the mission. Improving our scientific understanding often goes hand-in-hand with improving the technology of our scientific instrumentation. Hence, UCLA's strong interest over the years in continuing to develop science-grade magnetometers. The DSX mission clearly benefits from this extensive heritage in scientific instrumentation. Moreover, UCLA's effort will contribute to the operational goals of DSX, which allows UCLA to provide an immediate societal benefit. This return of investment for the nation is also important for UCLA, allowing us to show the value in conducting basic research.

The magnetometer is essential for fully characterizing the particle and wave data to meet the Space Weather and WPIx goals. However, in addition to the supporting role of the magnetometer, the data provided by the instrument will clearly be a valuable resource for the Space Physics Community on its own. At UCLA, our scientific efforts are centered around the observations of magnetic fields due to current systems in the Earth's ionosphere and magnetosphere and to the ULF wave environment. There have been very few spacecraft with research-quality vector magnetometers flown in MEO. Therefore, the DSX mission will be ground-breaking in terms of providing information about the Earth's geomagnetic field and ULF wave environment in the inner magnetosphere.

The MEO magnetospheric regime has not been extensively studied because most scientific satellites are either in LEO-Low Earth Orbit (e.g., SAMPEX), HEO-highly elliptical orbit (e.g., SCATHA, AMPTE, ISEE 1/2), or at GEO-Geosynchronous orbit (e.g., GEOS 2, the LANL spacecraft). MEO covers a range of interesting space physics regimes including the radiation belts, the ring current, and the plasmasphere, and is home to a growing number of satellites (such as GPS) thus understanding the MEO space weather environment is becoming more and more important [e.g., *Le and Russell,* 1993].

2.2. The DSX Mission VMAG Science Objectives

The specific region of the magnetosphere to be explored by the DSX satellite between 10,000- and 20,000-km altitude (L between 1.5 to 3.1) is now known to be an extremely dynamic region overlapping the radiation belt slot, a region where the plasmapause often resides, and a place of intense wave activity [e.g., *Baker et al.,* 1994, *Moldwin et al.,* 2002, *Bortnik et al.,* 2003, *O'Brien et al.,* 2003]. The location of the inner edge of the outer radiation belts and the plasmapause has been found to be highly correlated [e.g., Li et al., 2006]. Figure 1 shows this correlation using data from SAMPEX and the O'Brien and Moldwin model for the location of the plasmapause. This correlation suggests that the plasmasphere plays a role in the loss of the energetic electrons. However, in addition, it has been shown in a model that radiation belt electrons of energies of > 1 MeV can be energized by ring current ion driven ULF waves just outside the plasmapause [Ozeke and Mann, 2008]. The DSX mission will be able to directly test these results.

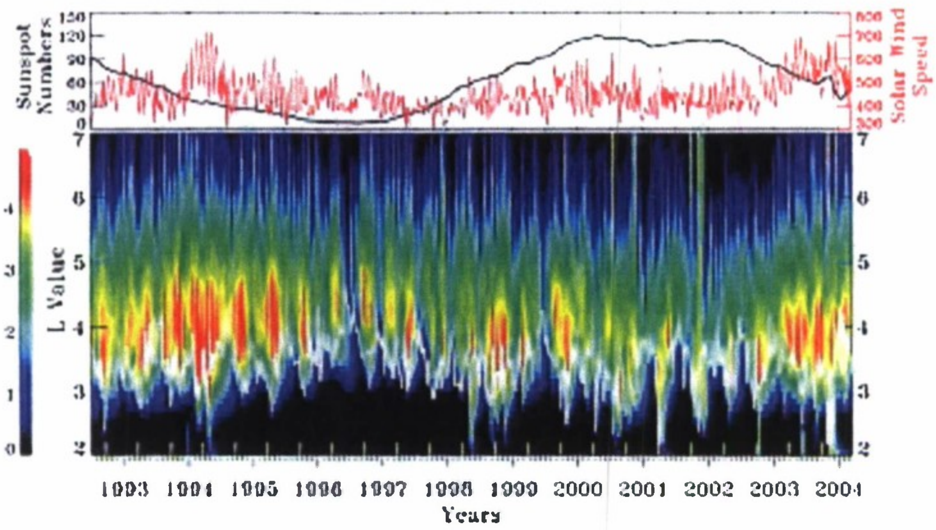


Figure 1. (top) Variations of yearly window-averaged sunspot numbers (black curve) and weekly window-averaged solar wind speed (km/s, red curve). (bottom) Monthly window-averaged, color-coded in logarithm, and sorted in L (L bin: 0.1) electron fluxes of 2–6 MeV (#/cm2-s-sr) by SAMPEX since its launch (July 3, 1992) into a low-altitude (550 × 600 km) and highly inclined (82°) orbit. The superimposed white curve represents every 10-day's minimum Lpp based on an empirical model [O'Brien and Moldwin, 2003]. The yellow vertical bars on the horizontal axis are marks of equinoxes.

In addition, DSX will provide the study of ring current dynamics and field-aligned currents (FAC) from a unique perspective deep in the inner magnetosphere. Two specific questions to be addressed by DSX are (1) what is the ULF wave environment in the inner magnetosphere during severe geomagnetic storms and (2) what is the configuration of the inner magnetospheric magnetic field during storms? With one satellite, it is difficult to place the observations into global context – however, UCLA operates three mid-latitude magnetometer chains (MEASURE, SAMBA, and McMac) that span the DSX *L* shells and can be used to estimate the inner magnetospheric mass density, independently estimate the location of the plasmapause, and characterize the global ULF wave environment. The PI for this proposal is the PI for MEASURE and a co-PI for SAMBA and McMac.

These complementary ground-based datasets will be used in addressing both questions. Specifically, for question (1), we will compile a database of ULF wave power as a function of LT, Magnetic latitude, *L* shell, and geomagnetic activity (as indicated by Dst, Asym, SymH, Kp, and AE) by automatically calculating dynamic power spectra. The result will be similar to the survey of AMPTE data by *Anderson et al.* [1990], but will cover the inner magnetospheric region.

For question (2), a satellite in a 10,000 x 20,000 elliptical orbit would have an orbital period of about 3 hours and 20 minutes. This is comparable to the time scale of the main phase of a geomagnetic storm. Therefore, DSX will sample a range of local times during the main phase of each storm allowing for the examination of the evolution of the partial ring current for a variety of storms. Recent studies have shown that the inner magnetosphere can be severely distorted during geomagnetic storms due to the growth of the partial ring current [e.g., *Tsyganenko et al.*, 2003].

2.3. The UCLA VMAG Effort

This section provides information on the UCLA VMAG team, and the Statement of Work defining UCLA's effort.

2.3.1. The UCLA Team

The project team for the UCLA VMAG project is shown in Table 1.

Table 1. UCLA VMAG Project Team and Basic Responsibilities

Name	Role and Responsibilities
Dr. Mark Moldwin	PI, overall project oversight, interface to DSX PMO, coordination of efforts of various project members, science lead
Dr. Robert Strangeway	Science Team
Mr. Joe Means	Project Manager, Schedule, budget manager
Mr. Dave Pierce	Electrical Engineer Design
Ms. Kathryn Rowe	Systems Engineer Design and Testing
Mr. Don Dearborn	Digital Engineer Programming and Testing
Mr. William Greer	Electronic and Mechanical Technician Fabrication and Testing
Mr. Bob Snare	Q&A testing, magnetic cleanliness

3. YEAR IN REVIEW

3.1 Summary of Activities 2Q 2007

In April 2007 we began to build the engineering unit sensor. This entails the fabrication of the sensor coil housing, the sensor chassis, and winding the ring cores. The construction of the sensor cable and connectors are also part of this process.

During this quarter, essentially all of the spaceflight parts were ordered and received except for a few long-lead items. All parts were received by the end of the quarter or early in the 3rd quarter.

The cable connector test plan was developed and the cable connector was put through an environmental test. The reason for this was that MSI specified temperature limits were given for the Electronic Unit, the Sensor and the boom cable. Because of the original layout of the cable, this required a cable connector to be located on the boom away from the thermal covering and therefore would be exposed to extreme cold temperatures. No space-qualified connector had been tested and qualified at the -100 °C range. Therefore we proposed to test the spaceflight connector to the temperature range specified by the PMO, but well beyond the manufacturer's testing limits.

The following are the results for the connector qualification:

- 6 connectors went through thermal cycling at a southern Californian test facility on 4/18/07
- All connectors passed visual inspection
- Connectors were thoroughly cleaned
- The 6 connectors went through the Dielectric Withstanding Voltage with all adjacent pins (4/26/07 to 4/27/07)
- All 6 connectors passed with a maximum leakage current of 0.126mA (specifications allows up to 2mA)
- All connectors passed visual inspection

Since the connectors passed, we will proceed to use this connector part in our flight harness as we had planned. This was approved by the PMO in May of 2007.

For testing purposes, ATK (Aliant Techsystems Inc.) requested that we provide a mass model of the VMAG sensor so they can attach it to the boom during boom testing. The mass model had the same form factor and mass as the VMAG sensor. This mass model was built and delivered to ATK during the quarter.

The second unit Ground Support Equipment (GSE) fabrication was begun as well as the development of the thermal control design. Two GSEs are being built: one for testing of the systems at UCLA and one to be delivered to the project with the flight unit for integration and testing purposes. Figure 2 below shows the front panel of the first GSE.

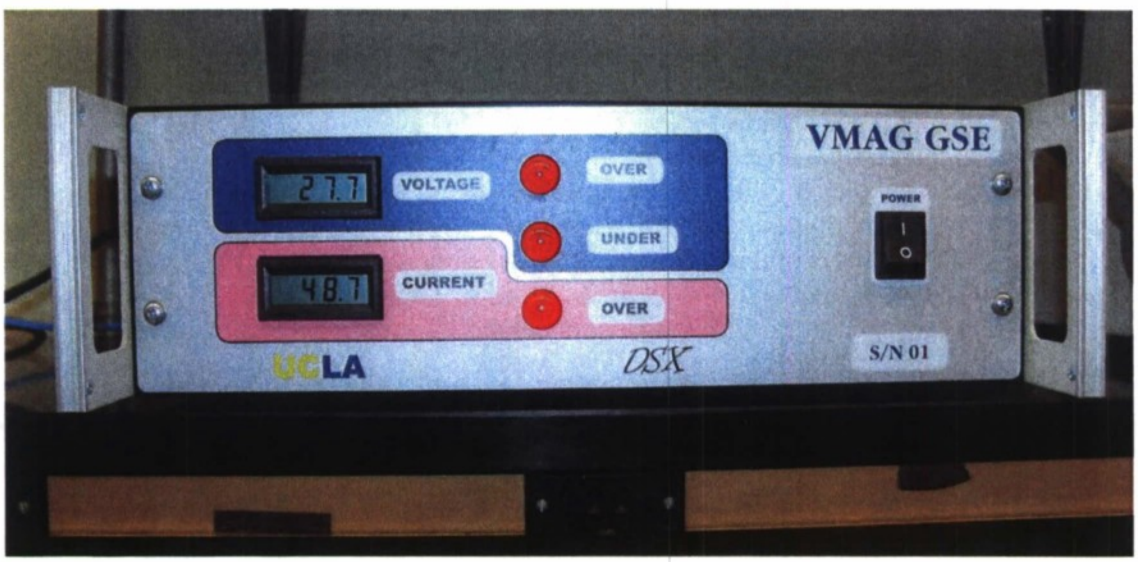


Figure 2. VMAG Ground Support Equipment (GSE) front panel.

At the end of May 2007, we achieved a project milestone of having a function engineering unit magnetometer. The Engineering Unit (EU) development in this quarter included the design and population of the board, and Field Programmable Gate Array (FPGA) programming. We also completed the fabrication of the engineering unit cable. The data from the engineering unit was well within specifications and Level 0/1 requirements for DSX and this gave us the confidence to proceed to development of the flight units.

In June 2007 we began the flight chassis fabrication and the flight sensor design. We also continued the 2nd Ground Support Equipment (GSE) build effort. In addition, Bob Snare worked closely with the PMO/MSI to develop a magnetic cleanliness plan revision. This also involved issues of magnetic cleanliness of other WPIx instrument payloads..

3.2 Summary of Activities 3Q 2007

In July and August the fabrication of the GSE Helmholtz coil was completed. A picture of these is shown in Figure 10. Most of this quarter work on VMAG was in hiatus due to the projects budget slow down. However, the Engineering Unit tuning was on-going to find the right design that fit the sensor, Engineering Electronics Unit (EEU) and cable.

3.3 Summary of Activities 4Q 2007

The main activity of the fourth quarter was the tuning and testing of the EEU. At the beginning of the quarter we were in hiatus due to the project's budget problems, but restarted our effort in mid-October. We hosted a site visit on October 10, 2007, with Lt. Dan Elsner and Maj. Kris Labowski. Lt. Elsner briefed us on the format of quarterly and annual reports and we gave a status report of our efforts and answered questions regarding our supplemental budget request.

The testing and tuning of the EEU was completed during the quarter. Figure 3 shows the VMAG sensitivity test result for 1-nT rms @ 1 Hz. This exceeds our design specifications and gave us confidence to proceed to development of the flight instrumentation. Note, the noise floor and rapid roll-off of response around the 1-nT signal.

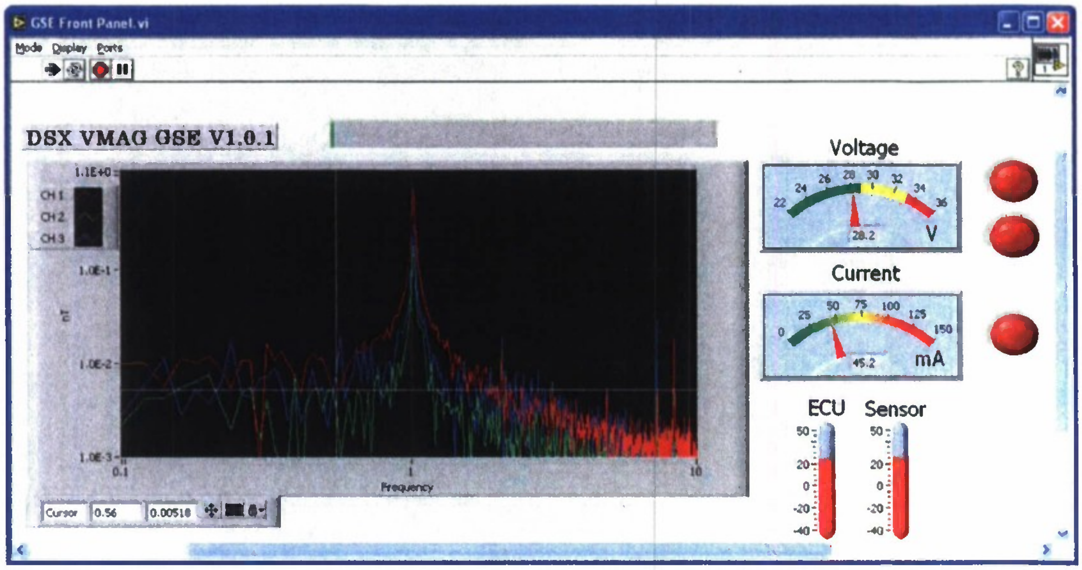
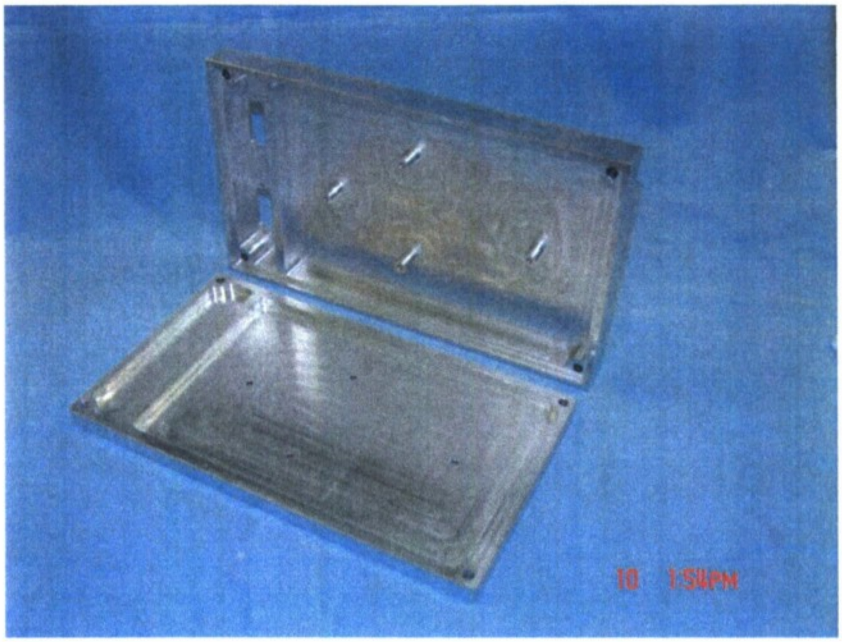


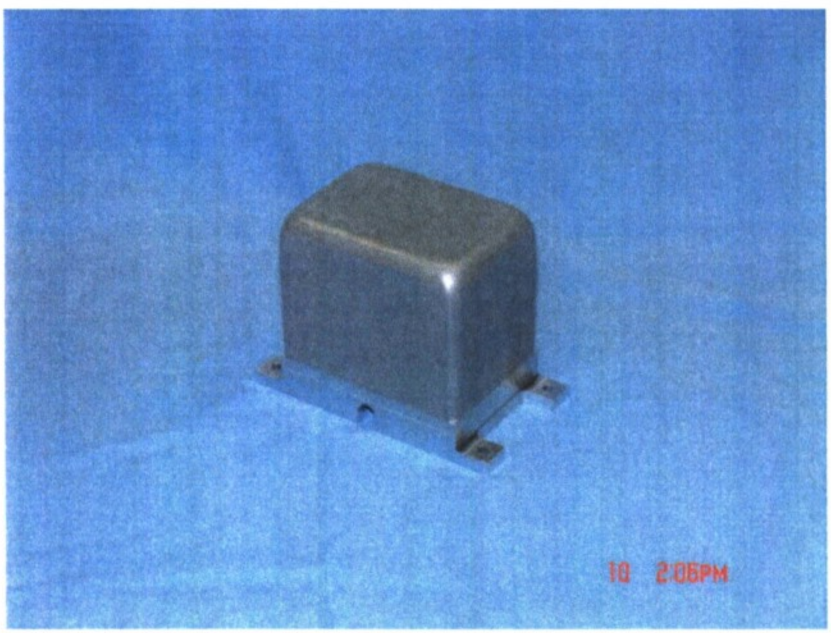
Figure 3. The VMAG GSE display showing the signal and noise floor of sensor.

Work on the refurbishment of the environmental test equipment was begun. See below for further discussion of this effort that involves both hardware and software development.

The assembly of the engineering sensor was begun and completed in the quarter as well. In anticipation of the flight unit fabrication, the flight unit electronic unit and sensor chassis were completed. These machined chassis are currently waiting to be sent out to be nickel plated and painted. The pictures below show the fabricated EU chassis and the sensor housing.



a)



b)

Figure 4. (a) The unpainted electronics unit chassis and (b) unpainted flight sensor cover.

At the start of the quarter, the VMAG team (Kathryn Rowe) also developed and submitted to the DSX Program Management Office (PMO) the documentation for the Functional Test Plan. The purpose of this document is to describe the procedure on how to demonstrate that the vector fluxgate magnetometer (VMAG) is functional during spacecraft integration and after environmental testing. Figure 5 below shows the short functional setup.

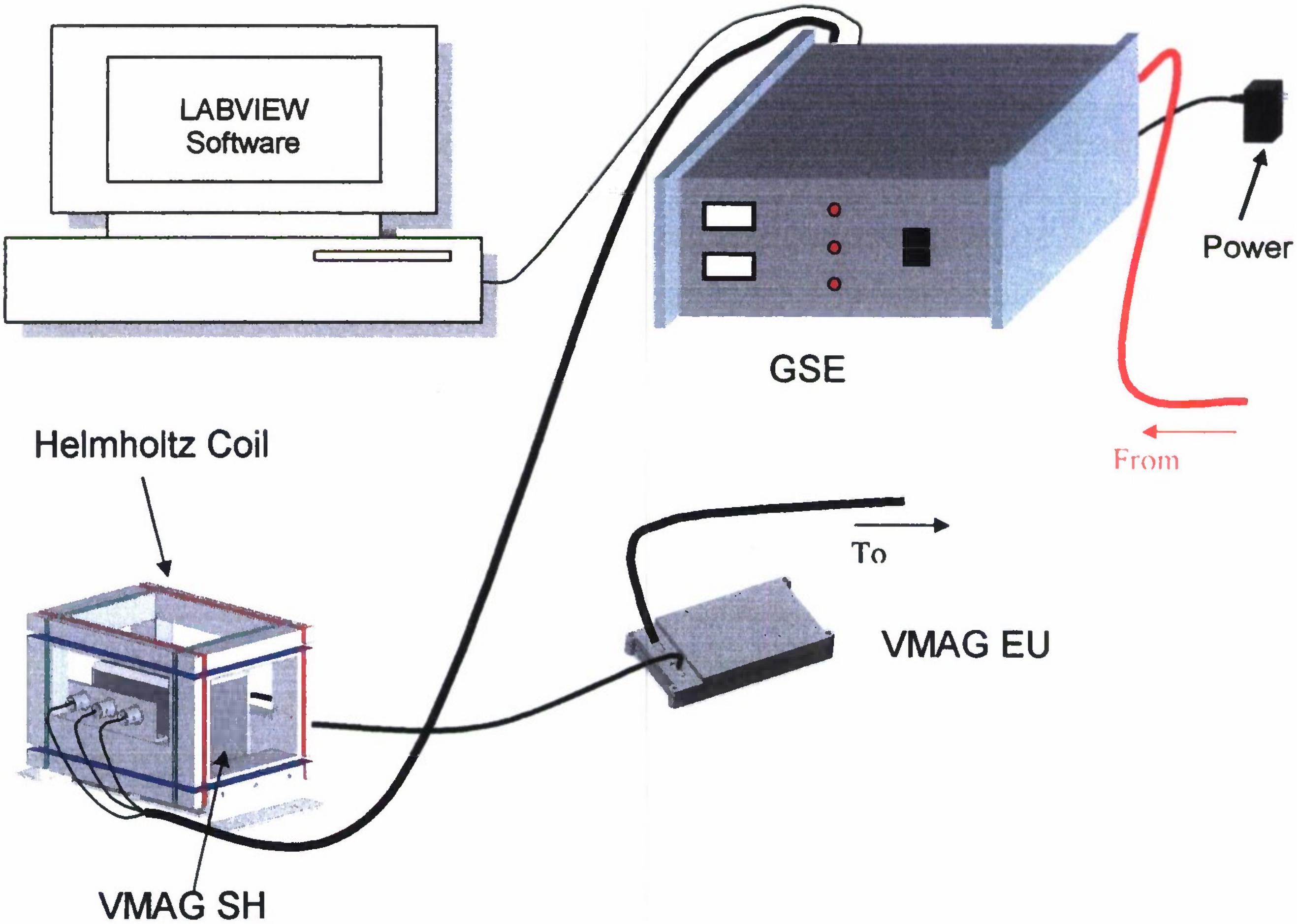


Figure 5. Short Functional Test Set-up

At the end of October, it was determined that the sensor cable layout would not allow the proper bending angle for the cable. It was redesigned, which required modifications to the ICD (new locations for cable connectors) and the change in the sensor mass model that was sent to ATK earlier in the year. These tasks were completed by mid-December and the new mass model was returned to ATK for their testing purposes on December 10, 2007. The ICD for the sensor pigtail is shown in Figure 6.

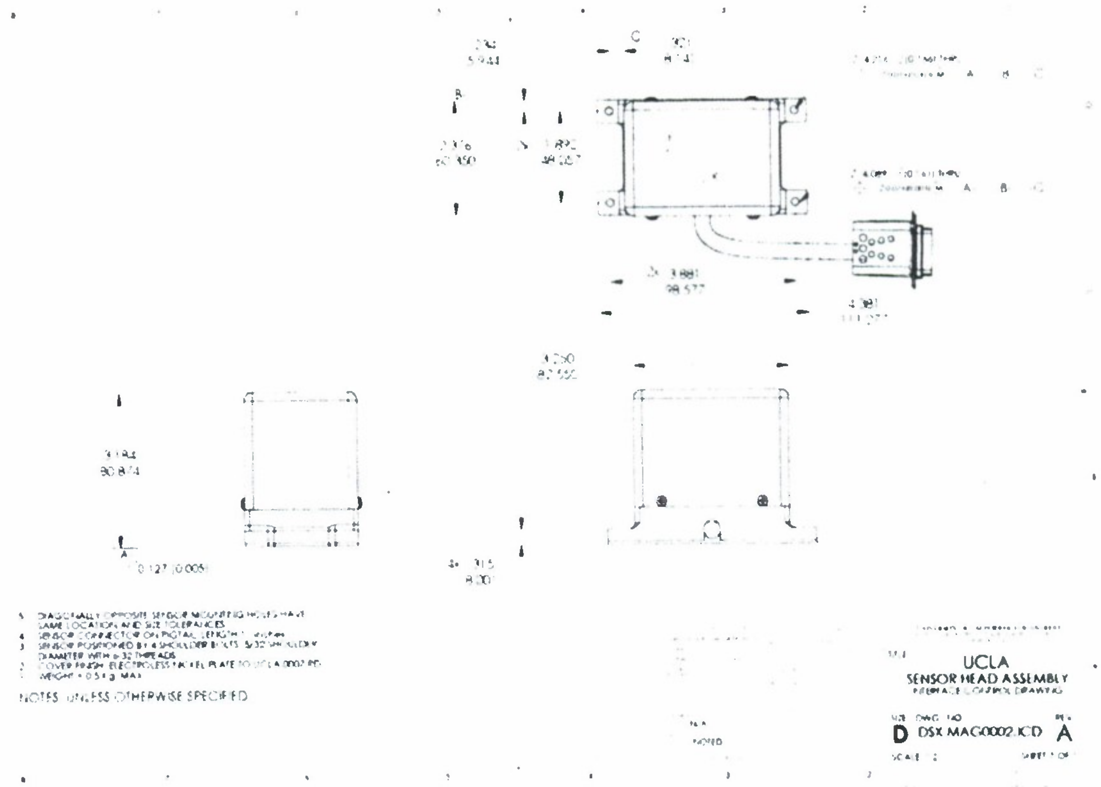


Figure 6. Instruction of mechanical ICD showing the pigtail and connector.

With the tuning of the Electronics engineering unit completed, Don Dearborn continued the FPGA design for the VMAG EU. In parallel with this effort and the thermal test equipment upgrade, work was begun on the fabrication of the 2nd GSE module.

Several risk items appeared during the quarter. One was the impact of the one-month slow down in August/September due to the DSX project's financial issues. This has forced the slippage of the flight unit delivery into the 2nd quarter of calendar 2008 and has essentially eliminated our schedule reserves. A second risk item was finding out that Thermount (used in the fabrication of the PCB) is no longer commercially available. After examining alternatives, it was decided to use Thermount for the fabrication of the flight EU and sensor boards and pay the new premium for the material. A third risk item that appeared at the end of the 4th quarter was the loss of one of our flight qualified mechanical and electrical technicians. Though he worked primarily on other projects, he was responsible for the upgrade of the thermal test equipment. We are currently assessing the potential schedule impact that this manpower issue will have on VMAG and may be added as a watch list item in early 2008. A new schedule is currently being developed by Joe Means at the request of the PMO.

3.4 Summary of Activities 1Q 2008

The main activity of the first quarter was completing the development of the Engineering Electronics Unit (EEU) and beginning the fabrication of the flight unit electronics and chassis. A number of fabrication and testing issues arose during the quarter, but all of them have been resolved with minimal impact on the expected flight unit delivery later this year.

Work on the refurbishment of the environmental test equipment was completed during the quarter. The main aspect of this work was the re-work of the thermal test equipment. The in-house thermal test equipment is needed to run the engineering unit through its thermal test cycles. The old equipment did not have a good control system and therefore required careful attention during the testing. The new Labview-based controller allows more robust control of the thermal cycling.

The flight unit electronic unit and sensor chassis were completed during the 4rth quarter of 2007. During the most recent quarter, the chassis were sent out for nickel plating and painting. The pictures shown in Figure 4 are the fabricated EU chassis and the sensor housing prior to painting.

The following pictures show the nickel-plated and painted units. A major concern was that the chassis showed some pitting after the nickel-plating process. The units were sent to a second plating house for inspection and testing and it was learned that the pitting was due to improper plating procedures. So the units were cleaned and re-plated.

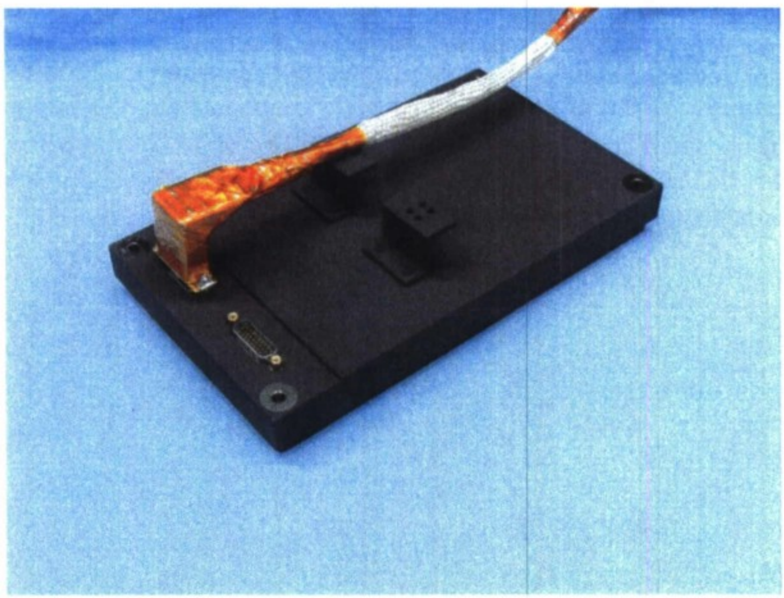


Figure 7. The painted electronic unit and cable.

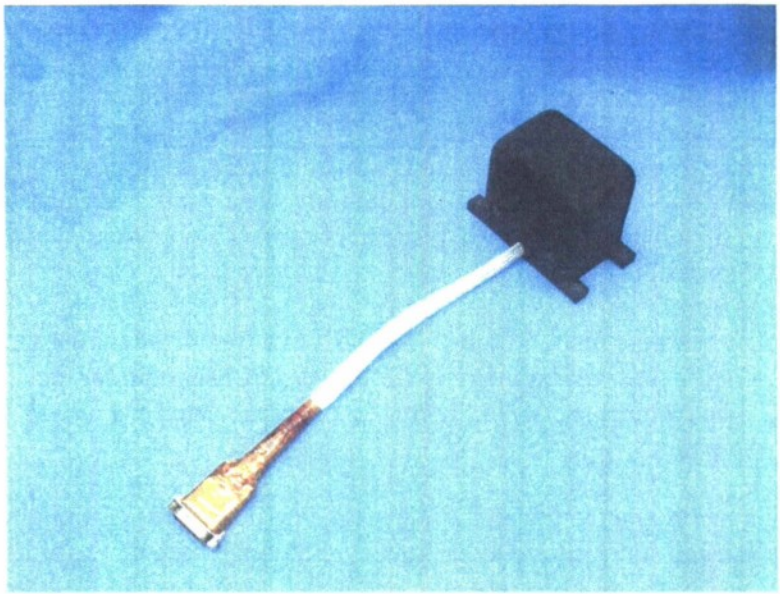


Figure 8. The painted sensor and cable pigtail connector.

As can be seen in Figures 7 and 8, the flight cables were also fabricated during this quarter. One delay was getting the final length of the cables from Microsat Systems Inc. (MSI). The fabrication included developing the sensor pigtail cable and re-working the Interface Control Document (ICD) to show the final cable length and bending angles. The schematic for the sensor pigtail is shown above in Figure 8. The VMAG team worked with MSI on finalizing the cabling, connectors, and backshell design. Figure 9 is the schematic with the connectors of the cable interface of the EU.

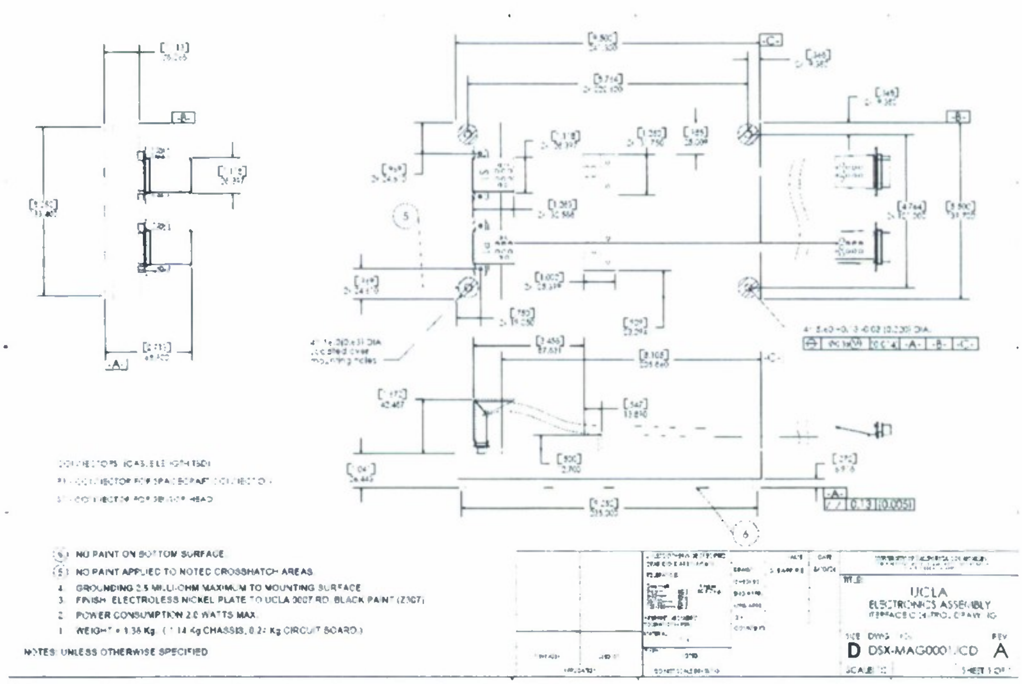


Figure 9. The electronics box mechanical ICD drawing showing the connectors.

With the tuning of the EEU completed, Don Dearborn continued the gate array design for the FPGA. This programming, testing, and porting of the code to the flight FPGA was completed during the quarter.

The flight unit PCB had a number of issues arise this quarter. The most serious was a de-lamination problem that occurred in the first two board spins. The thickness of the board was modified slightly and the board was successfully respun. The coupon/inspection process and delivery of the boards took place several weeks later than planned and therefore has impacted our schedule by those two weeks. A new schedule was submitted to the PMO that took into account the previous year's slow-down and the PCB board fabrication delays. The new board assembly is currently the primary task of the VMAG team. Parts preparation and the Assembly Instruction Data Sheets (AIDS) were completed in preparation of populating the board.

The VMAG team has also sought bids and placed orders for new magnetic shield cans to be used by the project during system testing and integration and a Walker magnetometer for magnetic cleanliness testing at the system level. It is anticipated that both of these items will arrive at UCLA prior to the system CDR in May, 2008. As part of the test plan, the VMAG team has developed a Helmholtz Coil that fits over the sensor so that it can be tested during system integration. Figure 10 shows this unit.

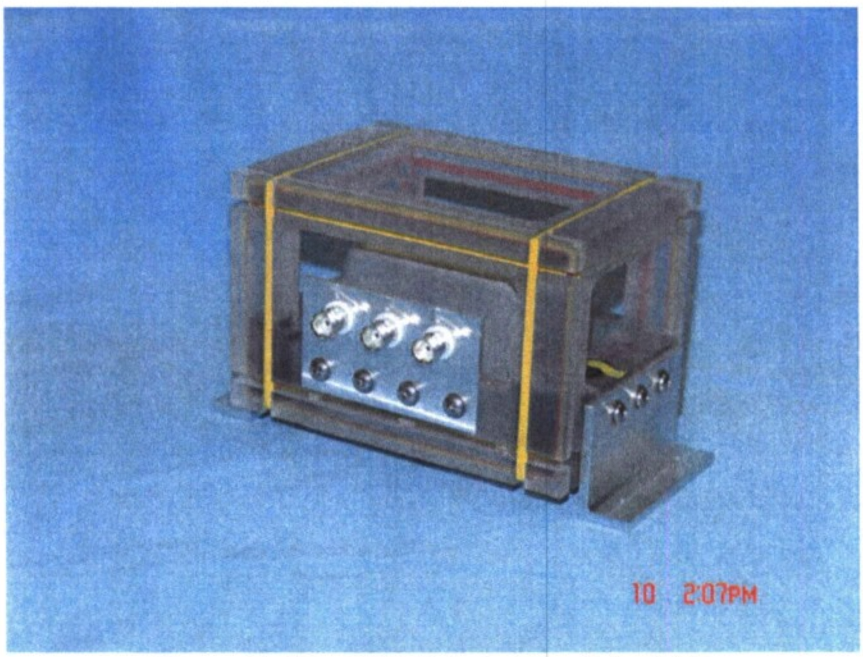


Figure 10. The GSE Helmholtz coil for I&T.

Several risk items appeared during the quarter, but have subsequently been resolved with relatively minor schedule impact. These include the PCB fabrication issues and the pitting of the chassis that were described above. The plan for the 2nd Quarter of

2008 is to nearly complete the fabrication and testing of the flight unit in preparation for a July 14, 2008 delivery. This contains one week of reserve.

4. CONCLUSIONS

The UCLA VMAG effort is well on its way towards delivery of flight hardware at the end of the 2nd or beginning of the 3rd quarter of calendar 2008. The Engineering Unit development, fabrication and testing indicates that the DSX vector magnetometer will perform better than the requirements and will contribute significantly to the science objectives of the mission.

REFERENCES

Le, G. and C. T. Russell, Effect of sudden solar wind dynamic pressure changes at subauroral latitudes: Time rate of change of magnetic field, *Geophys. Res. Lett., 20,* 1-4, 1993.

Li, X., D. N. Baker, T. P. O'Brien, L. Xie, and Q. G. Zong (2006), Correlation between the inner edge of outer radiation belt electrons and the innermost plasmapause location, Geophys. Res. Lett., 33, L14107, doi:10.1029/2006GL026294.

Moldwin, M. B., L. Downward, H. K. Rassoul, R. Amin[1], R. R. Anderson, A New Model of the Location of the Plasmapause: CRRES Results, *J. Geophys. Res., 107* (A11), 1339,
doi:10.102912001JA009211, 2002.

O'Brien, T. P., K. R. Lorentzen, I. R. Mann, N. P. Meredith, J. B. Blake, J. F. Fennell, M. D. Looper, D. K. Milling, and R. R. Anderson, Energization of relativistic electrons in the presence of ULF power and MeV microbursts: Evidence for dual ULF and VLF acceleration, *J. Geophys. Res.*, *108*(A8), 1329,
doi:10.1029/2002JA009784, 2003.

Ozeke, L. G., and I. R. Mann (2008), Energization of radiation belt electrons by ring current ion driven ULF waves, J. Geophys. Res., 113, A02201, doi:10.1029/2007JA012468.

Tsyganenko, N.A., H. J. Singer, and J. C Kasper, Storm-time distortion of the inner magnetosphere: How severe can it get? *J. Geophys. Res., 108*, SMP 18-1, CiteID 1209, DOI 10.1029/2002JA009808, 2003.

List of Symbols, Abbreviations, and Acronyms

A/D	analog to digital
ADC	analog to digital converter
AFGL	Air Force Geophysics Laboratory
AIDS	Assembly Instruction Data Sheet
AMPTE	Active Magnetospheric Particle Tracer Explorer
ATK	Aliant Techsystems Inc.
ATS	Applications Technology Satellite
CCE	Charge Composition Explorer
CVCM	Collected Volatile Condensable Material
CY	Calender Year
DOC	Department of Commerce
DOD	Department of Defense
DSRD	Draft Sensor Requirements Document
DSX	Demonstration and Science Experiments
ECS	Experiment Computer System
EDR	Environemental Data Record
EDU	Engineering Development Unit
EEU	Engineering Electronics Unit
EMC	Electromagnetic Compatability
EMI	Electromagnetic Interference
EU	Engineering Unit
FAC	Field-Aligned Current
FAST	Fast Auroral Snapshot Explorer
FedSat	Federation Satellite (Australia)
FPGA	Field Programmable Gate Array
FU	Flight Unit
FY	Fiscal Year
GEO	Geosynchronous Orbit
GEOS 2	Geosynchronous Orbit Scientific Satellite 2
GMR	Gross Magnetoresistive Resistor
GPS	Global Positioning System
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
I&T	Integration and Test
ICD	Interface Control Document
IGPP	Institute of Geophysics and Planetary Physics
IMF	Interplanetary Magnetic Field
IPO	Integrated Program Office
ISEE	International Sun-Earth Explorer
ISO	International Standardization Organization
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
LANL	Los Alamos National Laboratory
LSB	Least Significant Bit

McMac	Mid-Continent Magnetoseismic Chain
MEASURE	Magnetometers Along the Eastern Atlantic Seaboard for Undergraduate Research and Education
MEO	Medium-Earth Orbit
MSI	Microsat Systems Inc.
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPSL	NASA Parts Selection List
OGO	Orbiting Geophysical Observatory
PC	Personal Computer
PCAD	Personal Computer Aided Design
PDE	Principal Design Engineer
PET	Principal Electronic Technician
PF	Protoflight
PI	Principal Investigator
PPL	Preferred Parts List
PVO	Pioneer Venus Orbiter
QA	Quality Assurance
RDR	Raw Data Records
RF	Radio Frequency
RMS	Root mean square
SACI-1	Satélite de Aplicações Cientificas
SAMBA	South American Meridional B-field Array
SCATHA	Spacecraft charging at high altitude
SDE	Senior Development Engineer
SMALL	Sino Magnetic Array at Low Latitudes
SRD	Sensor Requirements Document
ST5	Space Technology 5
TID	Total Integrated Dose
TBS	To be Specified
TML	Total Mass Loss
UCLA	University of California Los Angeles
UCOP	University of California Office of the President
VMAG	Vector Magnetometer
WMM	World Magnetic Model